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SHORT COMMUNICATION

Process Identification for an SOPDT Model Using Rectangular Pulse Input

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Abstract−A new method of process identification for a second-order-plus-dead-time model is proposed and tested with two example systems. In the activation of the example processes for the identification, a rectangular pulse input is applied to open loop systems. The model parameters are estimated by minimizing sum of modeling errors with the least squares method. The estimation performance is examined by comparing the output pulse responses from the example system and the estimated model. The performance comparison of the proposed method and two existing techniques indicates that satisfactory parameter estimation is available from the proposed procedure. In addition, the role of sampling time and the shape of input pulse is evaluated and it is found that the sampling time of less than 0.01 minute gives good estimation while the shape of input pulse does not affect the estimation performance. Finally, the robustness of the estimation in noisy process is proved from the investigation of the performance in the processes having various levels of noise.

Key words: Process Control, Process Identification, Rectangular Pulse Technique, Second-Order-Plus-Dead-Time Model, Least Squares Estimation

INTRODUCTION

The conventional PID control is the most widely used control technique in chemical processes, but the necessity of an appropriate tuning of control parameters is a significant obstacle and many researches have been conducted to find a universal tuning technique. The technique requires complete knowledge of a process, and in general two types of process responses, frequency and transient responses, are utilized in process analysis. While most of the tuning techniques using frequency response do not require any knowledge of a process model, tuning procedures with transient response provide a process model and the tuning is carried out with the model. Therefore, the transient response tuning is heavily dependent on the process model. A minor unknown or incompletely known portion of the process, such as delay time, damping factor, time constant and steady state gain, causes difficulty in the tuning.

As a frequency response tuning technique the relay feedback method was proposed by Åström and Hägglund [1984], and many studies have reported the improvement of the technique. Meanwhile, Yuwana and Seborg [1982] introduced a proportional controller method using transient response. Huang and Huang [1993] and Rangaiah and Krishnaswamy [1994] extended the technique. Using time domain input-output information, Sung and Lee [1999] derived a general transfer function model. While the relay-feedback method results in persistent output oscillation, the P-controller techniques leave an offset from the initial steady state value. A rectangular pulse response technique [Ham and Kim, 1998] gives fast estimation without the oscillation and the offset.

Most transient response techniques, including a recent work [Huang et al., 2001], utilize several point data to calculate model parameters. The estimation is simple and easy, but it is prone to error with noisy output. Especially, an unstable ultimate response results in a large estimation error. On the other hand, though an integral method requires more computation, the effect of noise is much less significant.

Instead of a standard transfer function model, an autoregressive moving average (ARMA) model is employed in many studies. Because it has more parameters, better process description is available. Moreover, recursive parameter estimation reduces computational load and increases adaptability of the model. The recursive least squares method is widely employed in the techniques [Sagara et al., 1991; Johasson, 1994; Söderström et al., 1997; Garnier, 2000]. A performance evaluation of the methods is conducted from Söderström and Mossberg [2000]. As modified estimation methods from the techniques, Legendre polynomials [Hwang and Guo, 1984] and Laguerre expansion [Chou et al., 1999] are utilized in the development of process models. Also, an estimation in differentiation domain is presented by Kuznetsov et al. [1999]. In several studies [Whitfield and Messali, 1987; Sagara and Zhao, 1989; Sung et al., 1998], an integral method is applied to the least squares estimation with autoregressive models.

In this study, the pulse response technique is applied to the estimation of an SOPDT model utilizing time domain input and output data, and its estimation performance is compared with two existing estimation methods. Furthermore, the effect of sampling time, the shape of input pulse and noise contained in output signal is investigated by evaluating the integral of absolute errors for a variety of cases.

PARAMETER ESTIMATION

A general form of a second-order-plus-dead-time (SOPDT) process model is expressed as Eq. (1).

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$$G(s)=\frac{K_p e^{-\tau_d s}}{\tau^2 s^2+2\zeta\tau s+1} \quad (1)$$

where τ is time constant, K_p is process gain, ζ is damping factor and τ_d is dead time. The second-order Padé approximation is applied to the dead time, and Eq. (1) is simplified as a rational function form of transfer function. The Padé approximation leads to significant errors in a high frequency signal, such as noise, but the integral method of this study eliminates the effect of the noise and an error from the approximation is much less than that of other transient techniques.

$$G(s)=[K_p(\tau_d^2 s^2-6\tau_d s+12)]/[(\tau^2\tau_d^2)s^4+(6\tau^2\tau_d+2\zeta\tau\tau_d^2)s^3 +(12\tau^2+12\zeta\tau\tau_d+\tau_d^2)s^2+(24\zeta\tau+6\tau_d)s+12] \quad (2)$$

When an arbitrary shape of process response is yielded, the derivation of its Laplace transformation in simple form is difficult. Therefore, a time domain processing of the response is attempted in this study. The procedure is only applicable to a process in the initially steady state. The input-output relation from Eq. (2) in the Laplace domain is converted into time domain input-output relation [Yoo et al., 1999]. When terms of input are moved to the side of output terms, the whole equation equals to zero. But non-exact parameters lead to a residue; the residue at time t_j is calculated as

$$\Psi(t_j)=(\tau^2\tau_d^2)y_0(t_j)+(6\tau^2\tau_d+2\zeta\tau\tau_d^2)y_1(t_j) +(12\tau^2+12\zeta\tau\tau_d+\tau_d^2)y_2(t_j)+(24\zeta\tau+6\tau_d)y_3(t_j) +12y_4(t_j)-K_p[\tau_d^2 u_2(t_j)-6\tau_d u_3(t_j)+12u_4(t_j)] \quad (3)$$

where $y_i(t_j)=\frac{1}{(i-1)!}\int_0^{t_j}(t_j-t)^{i-1}y(t)dt$

$$u_i(t_j)=\frac{1}{(i-1)!}\int_0^{t_j}(t_j-t)^{i-1}u(t)dt$$

An objective to find the three parameters, τ, ζ and τ_d, in the SOPDT process model is formulated and it is

$$\text{Min.} \sum_{j=1}^{N}\Psi^2(t_j) \quad (4)$$

The number of samples is denoted as N. Since the process gain in the model is readily yielded from the ratio of integrals of output and input, it is omitted here. The input of this study is all positive values, and therefore the integral of output is of the integral of input multiplied by the process gain.

Least squares estimation is utilized to solve the problem. Partial differentiation of the objective with respect to the parameters gives a system of three algebraic equations, and the solutions of the equations are the desired parameters. For computational simplicity, Eq. (3) is separated into two vectors of process values and model parameters.

$$\Psi=\mathbf{VP} \quad (5)$$

where **V** is a vector of process values, the integrals of input and output in Eq. (3), and **P** is a vector of parameters, terms of parameters in Eq. (3). Since the parameters are only subjected to partial differentiation, the separation reduces the computational burden in the process of optimization. Then, the objective of Eq. (4) is written as

$$\sum\Psi^2=\mathbf{P}^T\sum(\mathbf{V}^T\mathbf{V})\mathbf{P} \quad (6)$$

and its partial derivatives are

$$\frac{\partial}{\partial\phi}(\sum\Psi^2)=\sum(\mathbf{V}^T\mathbf{V})\otimes\frac{\partial}{\partial\phi}(\mathbf{PP}^T) \quad (7)$$

where $\otimes$ indicates element-wise multiplication and summation and ϕ denotes one of model parameters. Because there are three parameters, we have three equations of Eq. (7) of which solutions are the parameters.

The system of equations is not exact, and therefore an optimization procedure or an iterative procedure can be applied for the solution of the minimization problem. In this study a symbolic method with "solve" command in the MATLAB toolbox is employed. The procedure does not require an initial estimation, and all default parameters are used.

Table 1. Estimated parameters and IAE's for process I with τ_d of 0.4 minute

τ	ζ	Parameter	Estimated value		
			Present	R & K	H & H
1	0.75	τ	1.0000	0.9996	1.0002
		ζ	0.7501	0.7500	0.7555
		τ_d	0.4000	0.4003	0.3996
		IAE	2.15E-4	4.94E-4	1.17E-3
	1.0	τ	0.9999	1.0000	1.0049
		ζ	1.0001	1.0004	0.9886
		τ_d	0.4000	0.3999	0.3986
		IAE	8.76E-5	6.96E-4	1.43E-3
	2.0	τ	0.9999	0.9998	1.0214
		ζ	2.0002	2.0005	1.9596
		τ_d	0.4000	0.3998	0.3939
		IAE	2.77E-5	1.82E-4	3.53E-3
2	0.75	τ	2.0000	2.0000	2.0020
		ζ	0.7500	0.7498	0.7551
		τ_d	0.4000	0.3999	0.3979
		IAE	0.0	8.74E-4	2.01E-2
	1.0	τ	2.0000	2.0000	2.0097
		ζ	1.0000	1.0004	0.9886
		τ_d	0.4000	0.3997	0.3977
		IAE	0.0	9.42E-4	1.82E-2
	2.0	τ	2.0000	2.0016	2.0423
		ζ	2.0001	1.9600	1.9600
		τ_d	0.4000	0.4000	0.3875
		IAE	1.27E-4	3.04E-4	3.28E-3
5	0.75	τ	5.0000	4.9977	5.0009
		ζ	0.7500	0.7500	0.7555
		τ_d	0.4000	0.4012	0.3982
		IAE	0.0	9.48E-4	8.72E-3
	1.0	τ	5.0000	5.0004	5.0247
		ζ	1.0000	1.0004	0.9886
		τ_d	0.4000	0.3990	0.3929
		IAE	0.0	4.33E-4	4.05E-3
	2.0	τ	5.0001	5.0029	5.1069
		ζ	2.0000	1.9991	1.9596
		τ_d	0.4000	0.3972	0.3693
		IAE	3.60E-5	4.61E-4	5.24E-3

EXAMPLE PROCESSES

Two processes are employed as examples to investigate the performance of process identification of this study, and the outcome is compared with the results of other methods.

Process I

$$G_1(s) = \frac{e^{-\tau_d s}}{\tau^2 s^2 + 2\zeta\tau s + 1} \quad (8)$$

Process II

$$G_2(s) = \frac{e^{-\tau_d s}}{(\tau^2 s^2 + 2\zeta\tau s + 1)(0.15s + 1)(0.1s + 1)} \quad (9)$$

The process I is an exact SOPDT model, and therefore estimation result is directly verified. The process II of a higher order process is also included in the evaluation of the identification performance. In both processes, process gain is eliminated since its computation is simple and independent to the estimation of other parameters.

RESULTS AND DISCUSSION

In process I with varying damping factor between 0.75 and 2, which represents under-damped, critically damped and over-damped systems, the outcomes of estimation of this study, Rangaiah and Krishnaswamy [1994] and Huang and Huang [1993] are listed in Tables 1 through 3. In the tables, three different time constants and

Table 2. Estimated parameters and IAE's for process I with τ_d of 1 minute

τ	ζ	Parameter	Estimated value		
			Present	R & K	H & H
1	0.75	τ	1.0003	0.9992	1.0005
		ζ	0.7500	0.7502	0.7555
		τ_d	0.9997	1.0004	0.9993
		IAE	3.10E-4	8.21E-4	1.18E-2
	1.0	τ	1.0005	1.0007	1.0040
		ζ	0.9997	1.0000	0.9893
		τ_d	0.9996	0.9994	0.9991
		IAE	1.84E-4	8.71E-4	1.41E-2
	2.0	τ	1.0023	0.9921	1.0224
		ζ	1.9960	2.0140	1.9579
		τ_d	0.9990	1.0038	0.9934
		IAE	2.34E-4	4.23E-4	3.35E-3
2	0.75	τ	2.0001	2.0000	2.0020
		ζ	0.7500	0.7498	0.7551
		τ_d	0.9999	0.9999	0.9979
		IAE	8.73E-5	7.99E-4	1.91E-2
	1.0	τ	2.0002	2.0000	2.0097
		ζ	0.9999	1.0004	0.9886
		τ_d	0.9999	0.9997	0.9977
		IAE	6.40E-5	8.69E-4	1.65E-2
	2.0	τ	2.0009	1.9984	2.0423
		ζ	1.9992	2.0016	1.9600
		τ_d	0.9997	1.0000	0.9875
		IAE	9.88E-5	3.15E-4	2.97E-3
5	0.75	τ	5.0002	4.9977	5.0009
		ζ	0.7500	0.7500	0.7555
		τ_d	0.9999	1.0012	0.9982
		IAE	7.29E-5	8.18E-4	7.21E-3
	1.0	τ	5.0002	5.0004	5.0247
		ζ	1.0000	1.0004	0.9886
		τ_d	0.9999	0.9990	0.9929
		IAE	6.06E-5	3.62E-4	3.11E-3
	2.0	τ	5.0005	5.0029	5.1069
		ζ	1.9998	1.9991	1.9596
		τ_d	0.9999	0.9972	0.9693
		IAE	3.10E-5	4.57E-4	4.92E-3

Table 3. Estimated parameters and IAE's for process I with τ_d of 2 minutes

τ	ζ	Parameter	Estimated value		
			Present	R & K	H & H
1	0.75	τ	0.9994	0.9992	1.0005
		ζ	0.7504	0.7502	0.7555
		τ_d	2.0002	2.0004	1.9993
		IAE	5.97E-4	8.16E-4	1.17E-2
	1.0	τ	0.9996	1.0007	1.0040
		ζ	1.0005	1.0000	0.9893
		τ_d	2.0000	1.9994	1.9991
		IAE	4.14E-4	8.80E-4	1.37E-2
	2.0	τ	1.0028	0.9921	1.0224
		ζ	1.9954	2.0140	1.9579
		τ_d	1.9985	2.0038	1.9934
		IAE	4.05E-4	4.18E-4	2.96E-3
2	0.75	τ	1.9994	2.0000	2.0020
		ζ	0.7502	0.7498	0.7551
		τ_d	2.0005	1.9999	1.9979
		IAE	2.05E-4	7.13E-4	1.69E-2
	1.0	τ	1.9993	2.0000	2.0097
		ζ	1.0003	1.0004	0.9886
		τ_d	2.0004	1.9997	1.9977
		IAE	1.51E-4	7.32E-4	1.35E-2
	2.0	τ	1.9964	1.9984	2.0423
		ζ	2.0033	2.0016	1.9600
		τ_d	2.0015	2.0000	1.9875
		IAE	1.49E-4	3.14E-4	2.70E-3
5	0.75	τ	4.9997	4.9977	5.0009
		ζ	0.7501	0.7500	0.7555
		τ_d	2.0003	2.0012	1.9982
		IAE	1.11E-4	6.23E-4	5.03E-3
	1.0	τ	4.9996	5.0004	5.0247
		ζ	1.0001	1.0004	0.9886
		τ_d	2.0003	1.9990	1.9929
		IAE	4.80E-5	2.63E-4	1.86E-3
	2.0	τ	4.9975	5.0029	5.1069
		ζ	2.0010	1.9991	1.9596
		τ_d	2.0010	1.9972	1.9693
		IAE	4.38E-5	4.16E-4	4.31E-3

three dead times are utilized. Since the process has an exact SOPDT model, direct examination of the estimated process parameters from the three techniques is available. For the numerical comparison of the estimation, the integral of absolute errors (IAE) is computed and included in the tables. The integral of squared error (ISE) can be utilized in the comparison, but it has less significance in small errors than the IAE. In this study the errors are small numbers. The IAE is calculated from the differences in the step response of the SOPDT model having known parameters and estimated ones from the proposed techniques. The IAE's of this study in all damping factors are the least among three estimation methods, which indicates that the present technique is the most efficient.

The same procedure is applied to a higher order process, the process II, and the outcome is listed in Tables 4 through 6. In the comparison of the IAE, the result of this study is a little worse than Rangaiah and Krishnaswamy [1994]'s work for the damping factor of one or less at a long time constant, but this study shows better performance for the factor of two. In all damping, this study gives better performance than Huang and Huang [1993]. When it is considered that most chemical processes exhibit a behavior of over-damped response, the present technique is more useful than the existing ones because it shows better performance with high damping factor.

For the best performance of the present estimation, the sampling time and shape of rectangular input pulse are examined by comparing the IAE's from various sampling time and input shapes. The input pulse has a width of one minute and height of one. Fig. 1 il-

Table 4. Estimated parameters and IAE's for process II with τ_d of 0.4 minute

τ	ζ	Parameter	Estimated value		
			Present	R & K	H & H
0.5	0.75	τ	0.5225	0.5558	0.6320
		ζ	0.7652	0.7195	0.6697
		τ_d	0.6003	0.5826	0.5264
		IAE	1.76E-2	2.65E-2	8.61E-2
	1.0	τ	0.5467	0.5569	0.5599
		ζ	0.9717	0.9538	0.9397
		τ_d	0.5876	0.5864	0.5856
		IAE	1.04E-2	1.05E-2	1.74E-2
	2.0	τ	0.6604	0.6235	0.6314
		ζ	1.5887	1.6640	1.6486
		τ_d	0.5516	0.5772	0.5724
		IAE	2.91E-3	3.05E-3	4.68E-3
1	0.75	τ	1.0184	1.0292	1.0692
		ζ	0.7519	0.7407	0.7293
		τ_d	0.6177	0.6167	0.5864
		IAE	1.16E-2	1.47E-2	2.98E-1
	1.0	τ	1.0254	1.0320	1.0418
		ζ	0.9916	0.9861	0.9706
		τ_d	0.6166	0.6129	0.6076
		IAE	7.16E-3	7.00E-3	2.23E-2
	2.0	τ	1.1185	1.0544	1.0857
		ζ	1.8170	1.9114	1.8610
		τ_d	0.5848	0.6217	0.6090
		IAE	2.44E-3	2.57E-3	6.94E-3
2	0.75	τ	2.0146	2.0118	2.0320
		ζ	0.7492	0.7482	0.7492
		τ_d	0.6294	0.6361	0.6206
		IAE	5.04E-3	4.21E-3	2.12E-2
	1.0	τ	2.0208	2.0122	2.0245
		ζ	0.9951	0.9976	0.9849
		τ_d	0.6272	0.6375	0.6327
		IAE	3.70E-3	3.17E-3	1.93E-2
	2.0	τ	2.0722	2.0180	2.0702
		ζ	1.9392	1.9848	1.9374
		τ_d	0.6123	0.6406	0.6237
		IAE	1.48E-3	1.72E-3	3.90E-3

Table 5. Estimated parameters and IAE's for process II with τ_d of 1 minute

τ	ζ	Parameter	Estimated value		
			Present	R & K	H & H
0.5	0.75	τ	0.5281	0.5558	0.6320
		ζ	0.7628	0.7195	0.6697
		τ_d	1.1941	1.1826	1.1264
		IAE	1.80E-2	2.65E-2	8.60E-2
	1.0	τ	0.5435	0.5569	0.5599
		ζ	0.9751	0.9538	0.9397
		τ_d	1.1901	1.1864	1.1856
		IAE	1.05E-2	1.05E-2	1.74E-2
	2.0	τ	0.6594	0.6235	0.6314
		ζ	1.5909	1.6640	1.6486
		τ_d	1.1520	1.1772	1.1724
		IAE	2.90E-3	3.04E-3	4.64E-3
1	0.75	τ	1.0199	1.0276	1.0690
		ζ	0.7514	0.7416	0.7292
		τ_d	1.2163	1.2179	1.1863
		IAE	1.18E-2	1.38E-2	4.04E-2
	1.0	τ	1.0290	1.0281	1.0363
		ζ	0.9895	0.9877	0.9733
		τ_d	1.2137	1.2203	1.2162
		IAE	7.20E-3	6.07E-3	1.99E-2
	2.0	τ	1.1015	1.0584	1.0844
		ζ	1.8419	1.9052	1.8630
		τ_d	1.1928	1.2199	1.2096
		IAE	2.41E-3	2.68E-3	3.92E-3
2	0.75	τ	2.0127	2.0118	2.0320
		ζ	0.7498	0.7482	0.7492
		τ_d	1.2308	1.2361	1.2206
		IAE	5.18E-3	3.80E-3	2.11E-2
	1.0	τ	2.0213	2.0122	2.0245
		ζ	0.9949	0.9976	0.9849
		τ_d	1.2269	1.2375	1.2327
		IAE	3.64E-3	3.13E-3	1.75E-2
	2.0	τ	2.0622	2.0180	2.0702
		ζ	1.9479	1.9848	1.9374
		τ_d	1.2165	1.2406	1.2237
		IAE	1.51E-3	1.72E-3	3.74E-3

Table 6. Estimated parameters and IAE's for process II with τ_d of 2 minute

τ	ζ	Parameter	Estimated value		
			Present	R & K	H & H
0.5	0.75	τ	0.5438	0.5558	0.6320
		ζ	0.7613	0.7195	0.6697
		τ_d	2.1722	2.1826	2.1264
		IAE	2.59E-2	2.64E-2	8.59E-2
	1.0	τ	0.5394	0.5569	0.5599
		ζ	0.9804	0.9538	0.9397
		τ_d	2.1927	2.1864	2.1856
		IAE	1.14E-2	1.05E-2	1.74E-2
	2.0	τ	0.6514	0.6235	0.6314
		ζ	1.6074	1.6640	1.6486
		τ_d	2.1562	2.1772	2.1724
		IAE	3.26E-3	3.02E-3	4.56E-3
1	0.75	τ	1.0127	1.0276	1.0690
		ζ	0.7543	0.7416	0.7292
		τ_d	2.2223	2.2179	2.1863
		IAE	1.17E-2	1.36E-2	3.97E-2
	1.0	τ	1.0273	1.0281	1.0363
		ζ	0.9908	0.9877	0.9733
		τ_d	2.2145	2.2203	2.2162
		IAE	7.33E-3	5.84E-3	1.90E-2
	2.0	τ	1.1124	1.0584	1.0844
		ζ	1.8262	1.9052	1.8630
		τ_d	2.1871	2.2199	2.2096
		IAE	2.34E-3	2.62E-3	3.65E-3
2	0.75	τ	2.0070	2.0118	2.0320
		ζ	0.7510	0.7482	0.7492
		τ_d	2.2355	2.2361	2.2206
		IAE	5.35E-3	3.20E-3	2.03E-2
	1.0	τ	2.0149	2.0122	2.0245
		ζ	0.9973	0.9976	0.9849
		τ_d	2.2313	2.2375	2.2327
		IAE	3.80E-3	2.98E-3	1.43E-2
	2.0	τ	2.0594	2.0180	2.0702
		ζ	1.9503	1.9848	1.9374
		τ_d	2.2178	2.2406	2.2237
		IAE	1.47E-3	1.69E-3	3.54E-3

lustrates the variation of IAE with different sampling time for processes I and II. Different time constants, damping factors and dead times are applied for the investigation. The sampling time is scaled dividing with a time constant. In most cases, the performance with process I is satisfactory when a scaled sampling time of 0.01 or less is employed. This is true for process II. Therefore, it is recommended to set the scaled sampling time less than 0.01 or equal to it. However, processes I and II having long dead time compared with a time constant give poor performance.

The role of pulse area and aspect ratio, height to width ratio, of input pulse is examined by applying various pulses to the processes I and II and comparing the IAE's obtained with estimated parameters. Fig. 2 shows the variation of IAE with various aspect ratios

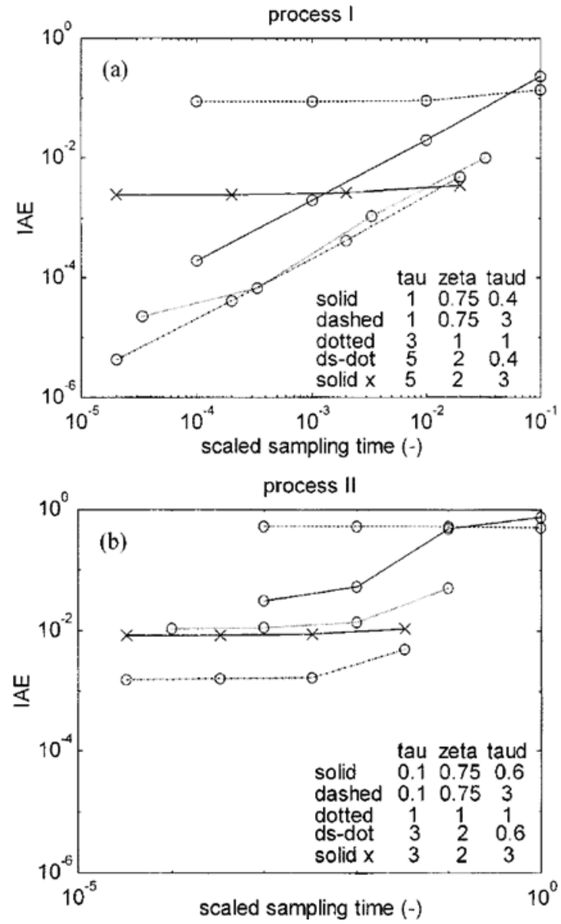

Fig 1. The variation of IAE with different sampling time in processes I and II.

in the process I for input pulse areas of 1 and 10. It indicates that the ratio and pulse area give no significant difference in the IAE. In other words, the aspect ratio and pulse area of input do not affect the performance of the present estimation as long as the output response is measurable. The same examination is conducted for process II and its outcome is illustrated in Fig. 3. Though the IAE's of process II are higher than those of process I, the conclusion of insignificant variation of IAE along with different aspect ratio and pulse area is also applied to process II.

In order to examine the estimation performance of the present technique in a noisy process output, a random noise is added to the output and the estimation is conducted. The computed IAE's with a variety of noise levels are depicted in Fig. 4. The output response is corrupted with a random noise having a given maximum value. In both processes, when less than 10 percent of peak output is added to the output as the maximum noise, the estimation is relatively satisfactory. Though the increase of the IAE is observed from 1 percent of the noise, the IAE with 10 percent noise is still satisfactory. Unless the noise level is unusually high, the proposed estimation technique is effective in noisy processes.

CONCLUSION

A parameter estimation technique utilizing rectangular pulse input

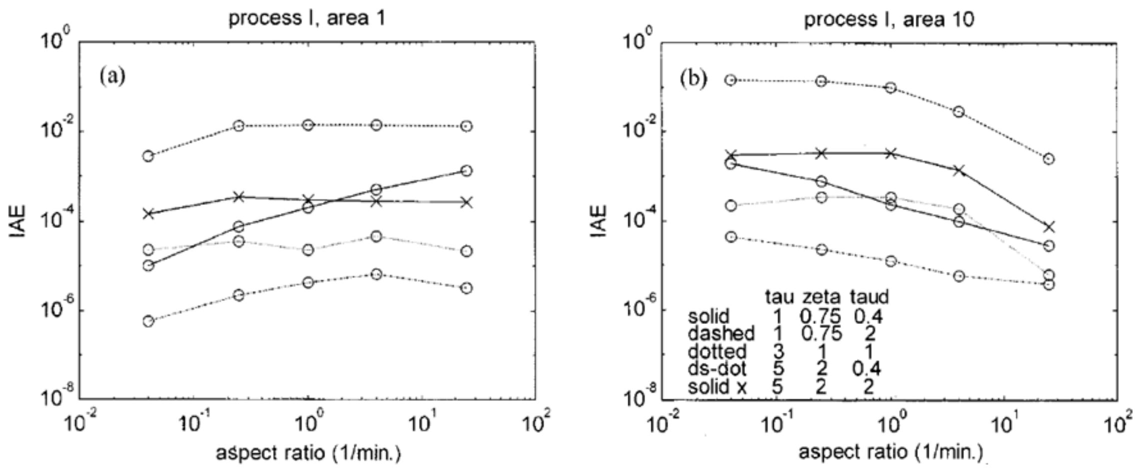

Fig. 2. The variation of IAE with different shape of input pulse in process I.

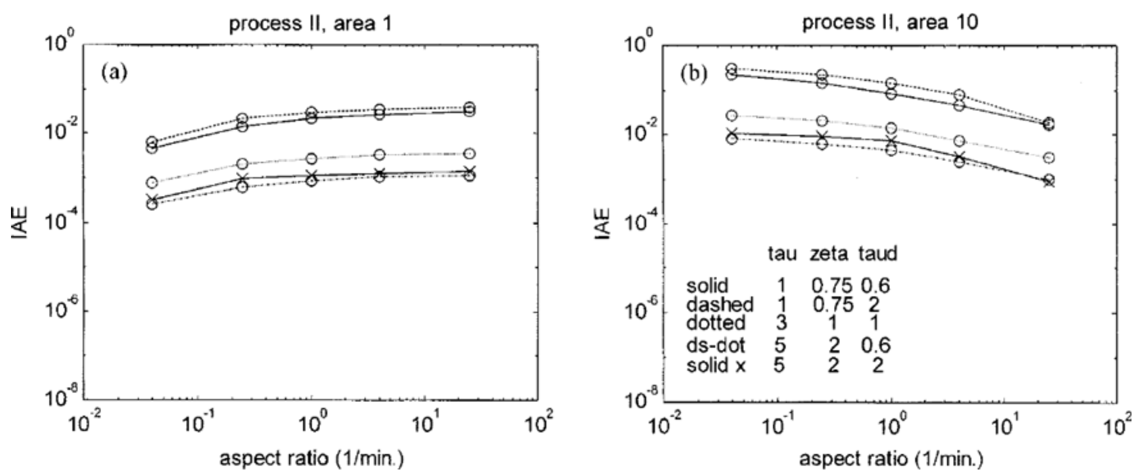

Fig. 3. The variation of IAE with different shape of input pulse in process II.

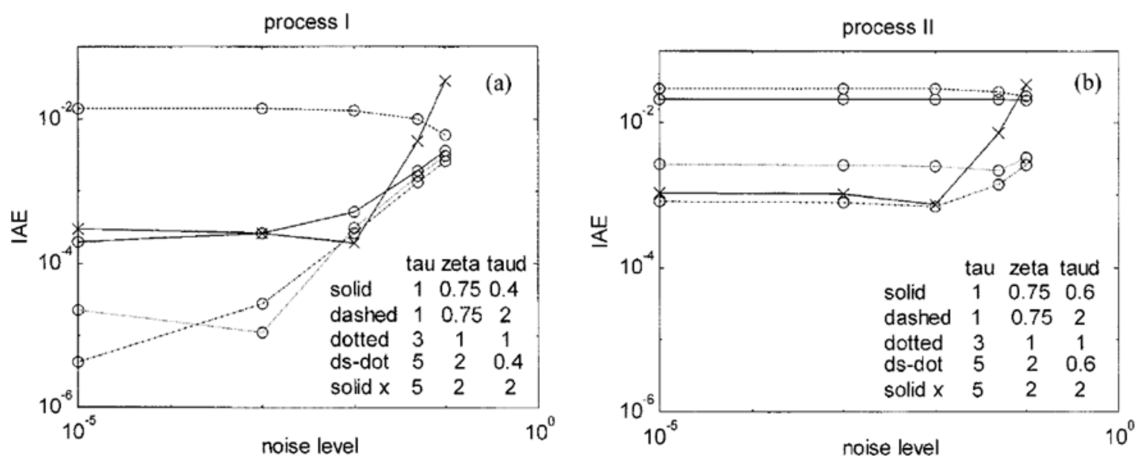

Fig. 4. The variation of IAE with different noise level in processes I and II.

is proposed and applied to two example processes. The technique analyzes the pulse output response using time domain computation and optimization, and gives a second-order-plus-dead-time model.

The estimation result is compared with those of two existing methods, and it is found that the proposed technique gives satisfactory parameter estimation. In addition, the role of sampling time and the shape of input pulse is examined along with the performance evaluation for noisy processes. The sampling time of less than 0.01 minute gives good estimation, and the shape of input pulse does not affect the estimation performance. Also, the maximum noise of less than 10 percent of the peak output does not impair the estimation performance of this study.

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NOMENCLATURE

K_p : process gain
P : parameter vector
s : Laplace parameter
V : process value vector

Greek Letters

ϕ : parameter
τ : time constant [min]
τ_d : dead time [min]
Ψ : residue defined in Eq. (3)
ζ : damping factor

REFERENCES

Åström, K. J. and Hägglund, T., "Automatic Tuning of Simple Regulators with Specifications on Phase and Amplitude Margins," *Automatica*, **20**, 645 (1984).

Chou, C. T., Verhaegen, M. and Johansson, R., "Continuous-Time Identification of SISO Systems Using Laguerre Functions," *IEEE Trans. Signal Process*, **47**, 349 (1999).

Garnier, H. Gilson, M. and Zheng, W. X., "A Bias-Eliminated Least-Squares Method for Continuous-Time Model Identification of Closed-Loop Systems," *Int. J. Control*, **73**, 38 (2000).

Ham, T. W. and Kim, Y. H., "Process Identification Using Pulse Response and Proportional Integral Derivative Controller Tuning with Combined Guidelines," *Ind. Eng. Chem. Res.*, **37**, 487 (1998).

Huang, C.-T. and Huang, M.-F., "Estimation of the Second-Order Parameters from the Process Transient by Simple Calculation," *Ind. Eng. Chem. Res.*, **32**, 228 (1993).

Hwang, C. and Guo, T.-Y., "Transfer-Function Matrix Identification in MIMO Systems via Shifted Legendre Polynomials," *Int. J. Control*, **39**, 807 (1984).

Johansson, R., "Identification of Continuous-Time Models," *IEEE Trans. Signal Process.*, **42**, 887 (1994).

Kuznetsov, A. G., Bowyer, R. O. and Clark, D. W., "Estimation of Multiple Order Models in the δ-Domain," *Int. J. Control*, **72**, 629 (1999).

Rangaiah, G. P. and Krishnaswamy, P. R., "Estimating Second-Order plus Dead Time Model Parameters," *Ind. Eng. Res.*, **33**, 1867 (1994).

Sagara, S. and Zhao, Z.-Y., "Recursive Identification of Transfer Function Matrix in Continuous Systems via Linear Integral Filter," *Int. J. Control*, **50**, 457 (1989).

Sarara, S., Yang, Z.-J. and Kiyoshi, W., "Recursive Identification Algorithms for Continuous Systems Using an Adaptive Procedure," *Int. J. Control*, **53**, 391 (1991).

Söderström, T., Fan, H., Carlsson, B. and Bigi, S., "Least Squares Parameter Estimation of Continuous-Time ARX Models from Discrete-Time Data," *IEEE Auto. Control*, **42**, 659 (1997).

Söderström, T. and Mossberg, M., "Performance Evaluation of Methods for Identifying Continuous-Time Autoregressive Processes," *Automatica*, **36**, 53 (2000).

Sung, S. W., Lee, I.-B. and Lee, J., "New Process Identification Method for Automatic Design of PID Controllers," *Automatica*, **34**, 513 (1998).

Sung, S. W. and Lee, I.-B., "On-line Process Identification and PID Controller Autotuning," *Korean J. Chem. Eng.*, **16**, 45 (1999).

Yoo, C.-K., Kwak, H. J., Sung, S. W. and Lee, I.-B., "An Estimation Method of SOPTD Model Parameter," *Theories and Application of Chem. Eng.*, **5**, 501 (1999).

Yuwana, M. and Seborg, D. E., "A New Method for On-Line Controller Tuning," *AIChE J.*, **28**, 434 (1982).

Whitfield, A. H. and Messali, N., "Integral-Equation Approach to System Identification," *Int. J. Control*, **45**, 1431 (1987).